Millimeter-Wave Active Antennas

and Spatial Power Combiners

Final Report

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Kai Chang

October 15, 1997

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13. ABSTRACT *(Maximum 200 words)*

This report summarizes the research activities carried out in the Electromagnetics and Microwave Laboratory, Department of Electrical Engineering, Texas A&M University. The project was sponsored by the U.S. Army Research Office under contract No. DAAH04-96-1-0372. The topics of investigation included mode stability in spatial power combining,active antenna transceivers and system applications, self-mixing active antennas, and novel uniplanar components. This final report for the period from August 1, 1996 through July 31, 1997 lists all the publications, which describe the supported research, along with the names of students who received the M.S. and Ph.D. degrees and contributed to the research.

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FOREWORD

This report summarizes the research activities carried out in the Electromagnetics and Microwave Laboratory, Department of Electrical Engineering, Texas A & M University. The project was sponsored by the U.S. Army Research Office under contract No. DAAH04-96-1-0372. The period of performance was from August 1, 1996 through July 31, 1997. The topics of investigation included mode and stability in spatial power combining, active antenna transceivers and system applications, self-mixing active antennas, and novel uniplanar components. The research has resulted in the publication of 1 book chapter and 10 papers.

Table of Contents

1. Introduction and Problems Studied

Active antennas have received a great deal of attention in the last ten to fifteen years due to their potential application to microwave and millimeter wave systems [1]. Although the concept has been around for several decades, active antennas have recently found applications in integrated transmitters, receivers, mixers, transponders, transceivers, and radar frontends. They have also been used in spatial power combining applications, where the radiated power of the system is increased by using an array of active radiators and using external injection-locking to achieve coherence. The increased interest stems from the fact that active antennas offer the potential of being fully integrated; which in turn leads to smaller, lighter, and perhaps less costly modules. As our understanding and experience with active antenna increases and as the technology for devices and integration matures, their performance and cost will determine their penetration into the commercial and military markets.

Although many quasi-optical active antennas and power combiners have been demonstrated, there is a lack of theoretical analyses to the accurate understanding of modes and their stability. The analysis is important for studying the effects of array coupling and phase noise.

To further reduce the size of a system, multiple-function active antenna is desirable. The antenna needs to be integrated with different solid-state devices like PIN, varactor, mixer diode, transistor to perform switching, tuning, modulation, mixing, and oscillating functions. A compact and low cost active integrated antenna transceiver was developed to demonstrate the multiple function capability. An FET oscillator and a mixer were integrated under an inverted patch antenna.

Self-mixing active antennas have been neglected because of the complex relationships involved in the design of a sensitive self-mixer and the impedance match to the antenna

structure. Even as recently as the mid-1990's, most research on self-mixing oscillators concentrated on the design and analysis of the mixer module, keeping the antenna as a separate entity. The simple, compact, and low cost self-mixing active antennas should be very attractive for many applications in wireless sensors, remote identification, and remote control.

Along with the research of the active antennas and spatial power combining techniques, work was also carried out on the novel planar slotline and coplanar waveguide circuit developments. The slotline and coplanar waveguide have the center conductor and ground planes on the same side of the substrate. They are truly uniplanar microwave integrated circuits that have the advantage of easy implementation of solid-state devices.

2. Summary of Results

The research was concentrated in four major areas: (1) mode and stability study in spatial power combining; (2) active antenna transceivers and system application; (3) self-mixing active antennas; and (4) novel uniplanar components. The results are summarized below.

2.1. Mode and Stability Study in Spatial Power Combining [2]

Spatial power combining is such a concept that by exciting the elements of an antenna array with signals of certain phase relationship directly from solid state RF power oscillators or amplifiers, a desired beam which contains most of the radiated power will be formed. Without extra cavities, transmission lines, and phase shifters, all of which cause losses, this method can achieve high combining efficiency.

Many spatial power combiners have been demonstrated, but there is a lack of theoretical analyses to study the modes and their stability. Most of the analyses were based on different overly simplified theoretical models, thus, failed to yield a complete,

consistent, and persuasive explanation to the modes and their stability of the promising coupled negative conductance oscillator driven spatial power combining arrays.

Therefore, in spite of those previous different analyses, it is still necessary to seek a unified treatment of the modes and their stability of the coupled negative conductance oscillator driven spatial power combining arrays. As an attempt to this end, modes and their stability of a symmetric two-element coupled negative conductance oscillator driven spatial power combining array, which is of the simplest form of all, have been considered theoretically. At first, the very general circuit equations of the symmetric two-element coupled negative conductance oscillator driven spatial power combining array are given in terms of the mutual admittance matrix of the array. It was shown that the two modes (one is in-phase, the other 180°-out-of-phase) of the symmetric two-element coupled negative conductance oscillator driven spatial power combining array are just two natural solutions of the circuit equations [2]. Then, by extending Kurokawa's theory on the stability of oscillators [3] [4], the stability of the two modes of the symmetric two-element coupled negative conductance oscillator driven spatial power combining array were studied thoroughly. Experiments done at C-band with a symmetric two-element coupled Gunn oscillator driven spatial power combining array demonstrated the validity of the theoretical analysis to a certain extent [2]. It is expected that the theory on the modes and their stability of any (symmetric or nonsymmetric) coupled negative conductance oscillator driven spatial power combining array with more than two elements can be developed from similar procedures.

2.2. Active Antennas Transceivers and System Applications [5]

To reduce the size and cost of a system, multiple-function active antennas are attractive. Several different types of solid-state devices can be integrated with an antenna to perform various functions. Figure 1 shows a transceiver made from the novel integration of

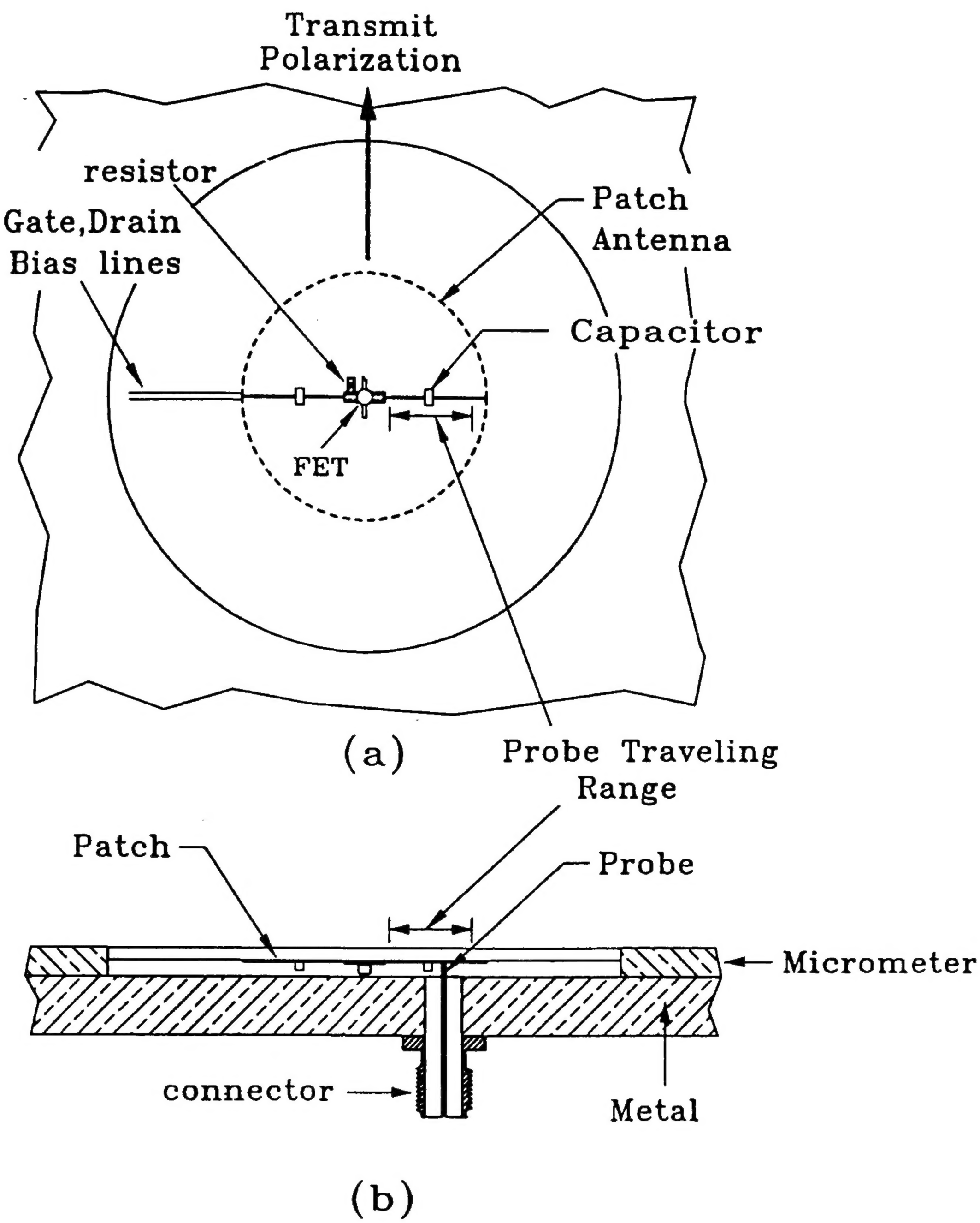

Figure 1. Active inverted stripline antenna with a probe placed in the cavity for measurement purposes. (a) Top view showing the active devices and the capacitors placed across the gap. (b) Side view showing the probe and the probe traveling range.

an FET and a mixer diode on the surface of an inverted patch antenna [5]. The FET is configured within the inverted patch structure to oscillate at C-band. The oscillator acts as a transmitter, and couples a portion of its power to the mixer thereby also acting as a local oscillator. The optimal position for placing the mixer diode on the patch is determined. A Schottky diode is placed within the antenna cavity, and it receives a portion of the oscillator power that mixes with an incoming RF signal. For a 5.8 GHz LO and a 6 GHz incoming RF signal, the 200 MHz intermediate frequency exhibits 5.5 dB isotropic conversion loss (L_{iso}). This structure is different from those presented because the active devices are placed directly onto the patch that eliminates the need for interconnect lines. This structure is then incorporated into a two-way communication system. The system demonstrates a calculated operating distance of 4.8 km for wireless communications.

The two-way communications system consists of two integrated active patch antenna transceivers shown in Figure 2. Each transceiver can be used to transmit and receive for simplex operation. The receive polarization is perpendicular to the transmit polarization for LO to RF isolation. One antenna can be rotated 90° with respect to the other, thus causing the transmit polarization for one transceiver to be equal to the receive polarization of the other transceiver. This allows for the polarization of a signal propagating in one direction to be perpendicular to a signal propagating in the opposite direction.

2.3. Self-Mixing Active Antennas

Recently, active antennas and self-mixing oscillators have attracted a lot of attention because they offer savings in size, weight, and cost over conventional designs. These features make them desirable for possible application in microwave communication systems such as local area networks (LANs), microwave identification systems, wireless

sensors, and short distance communication systems. Gunn diodes and FETs can operate as a self-mixing oscillators with conversion gains ranging from of 4.1 dB to 13 dB and with single sideband noise figures from 11.5 to as low as 3.3 dB [6]-[8]. Although the above-mentioned configurations deliver somewhat better circuit performance, they do so at the cost of increased circuit complexity. Gunn diodes are capable of delivering similar

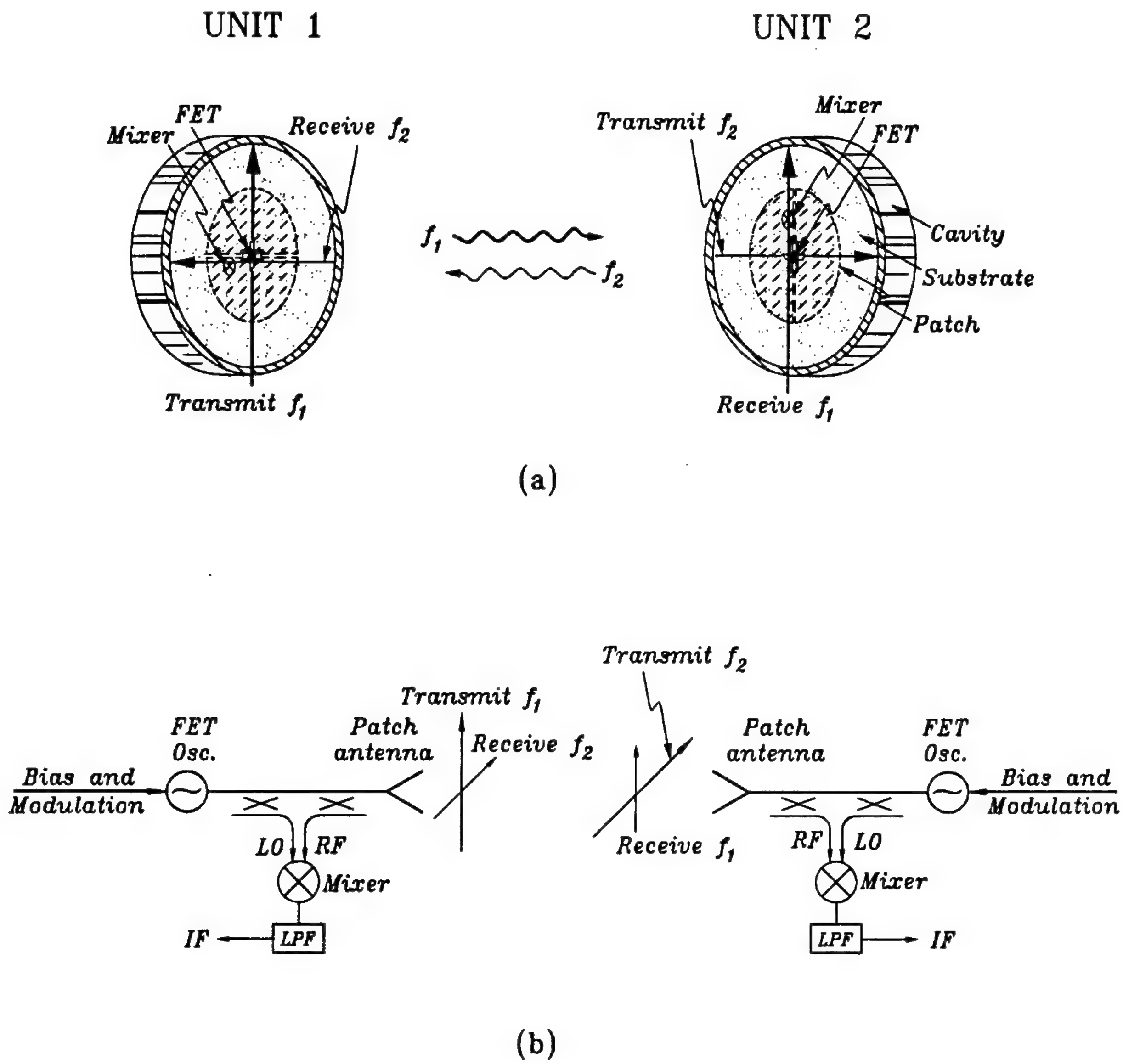

Figure 2. Two-way radio using active antennas. (a) configurations. (b) Block diagram.

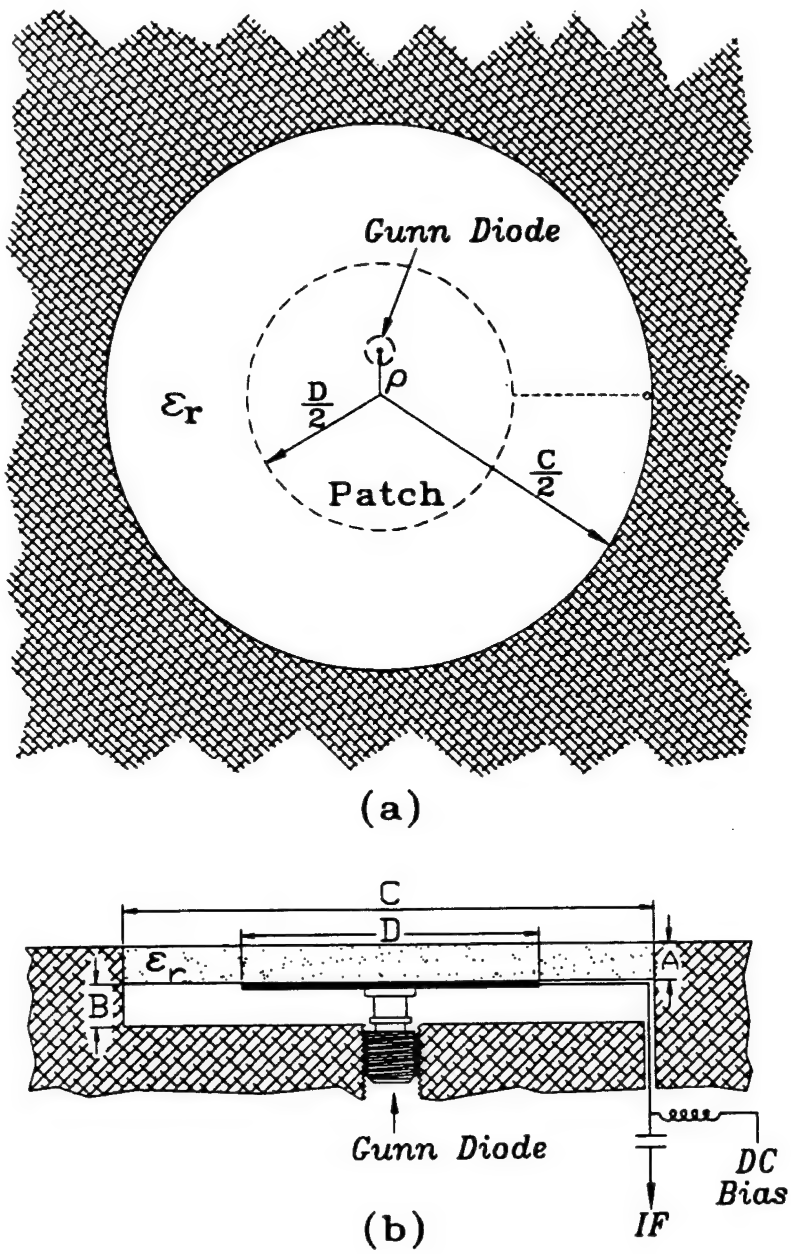

Figure 3. Configuration of a self-mixing active antenna. (a) Top view showing the Gunn diode placement and (b) side view showing the cavity depth, substrate thickness, DC bias, and IF output.

performance with a much simpler bias circuit. In this task a Gunn diode self-mixing oscillator was integrated with an inverted stripline antenna to form an active antenna configuration. The circuit as shown in Figure 3 consists of an active transmitter antenna and a Gunn diode oscillator used as the transmitter, local oscillator, and self-mixer. This configuration also allows for the addition of a varactor diode into the resonator cavity to provide electronic frequency tuning.

The active antenna radiates 14.8 ± 1 dBm over a bias tuning range of 200 MHz centered at 6.25 GHz for a bias tuning range of 3.8%. It can be operated as a self-mixing receiver with a conversion gain over 2 dB from 200 to 450 MHz and a single sideband noise figure of 12 dB at 200 MHz as shown in Figure 4 [9]. The antenna also has second-harmonic self-mixing capabilities, but in this case the mixer provides a conversion loss of 3.7 dB. This feature allows the active antenna to be used in identification systems that return a modulated second-harmonic signal, which simplifies transponder design since a microwave source is not needed.

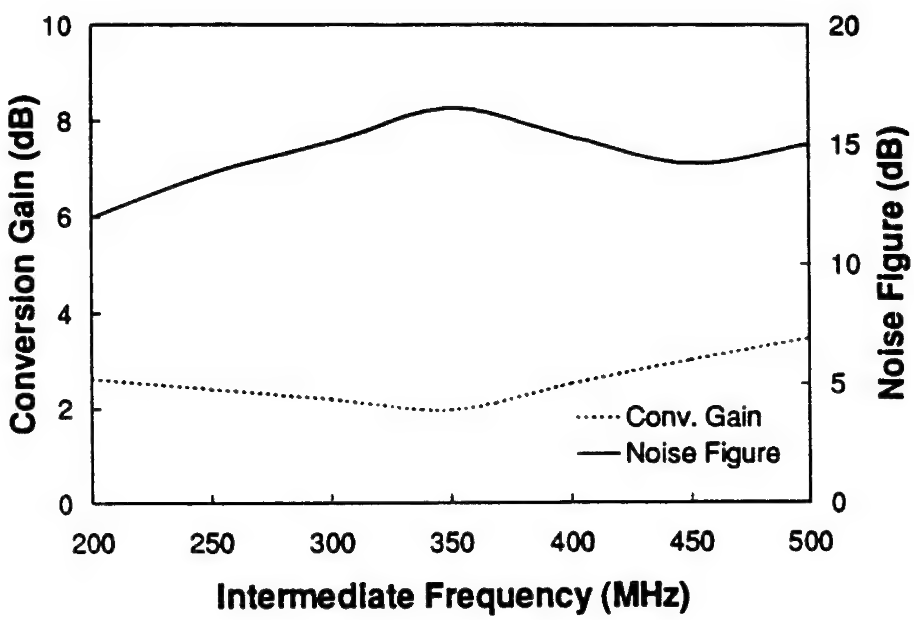

Figure 4. Conversion gain and noise figure of the self-mixing active antenna.

2.4. Novel Uniplanar Components [10,11]

Microstrip lines have been used as the main transmission lines in many MIC designs so far because the characteristics of microstrip lines are well known and a number of discontinuity problems have been analyzed. However, some shortcomings of microstrip include sensitivity to substrate thickness, difficulty in inserting shunt solid-state devices and the requirement of high impedance lines for dc biasing. In recent years, uniplanar transmission lines such as coplanar waveguide (CPW), coplanar strip (CPS) and slotline have become competitive alternatives to microstrip in many applications (including both microwave hybrid and monolithic technologies). These transmission lines have advantages of small dispersion, simple realization of short circuited ends, easy integration with lumped elements and active components, and no need for via holes. These characteristics make CPW, CPS and slotline important in MIC and MMIC designs. Many attractive components using uniplanar structures have been reported in the past 10 years, but almost all of them use symmetrical structures [12-19].

In order to further extend uniplanar techniques to MIC and MMIC applications, additional uniplanar components are required. New uniplanar power divider components have been developed with characteristics similar to those of microstrip circuits with the advantages of a uniplanar structure and better performance [10, 11]. Specifically, power dividers using one-section and two-section coupled CPW have been developed. These circuits provide substantially improved performance over a wider bandwidth than conventional microstrip power dividers. Measured results show that the one-section CPW power divider has greater than 20 dB isolation, less than 0.3 dB insertion loss, a 0.2 dB power dividing imbalance and a 2° phase imbalance over a bandwidth of more than 30% centered at 3 GHz. The two-section CPW power divider has greater than 24 dB isolation, less than 0.5 dB insertion loss, a 0.1 dB power dividing imbalance and a 1.6° phase imbalance over a bandwidth of more than 66% centered at 3 GHz. Experimental results agree well with calculated ones. In-phase and 180° out-of-phase power

dividers are constructed by the circuit configuration method. The even-odd mode excited method is used to analyze the power dividers. Also two other power dividers using asymmetrical coplanar strip (ACPS) have been developed with good performance. Figure 5 shows the circuit configurations. The 180° out-of-phase power divider provides an amplitude imbalance of 0.4 dB and a phase difference of 180° ± 1° over a wide bandwidth.

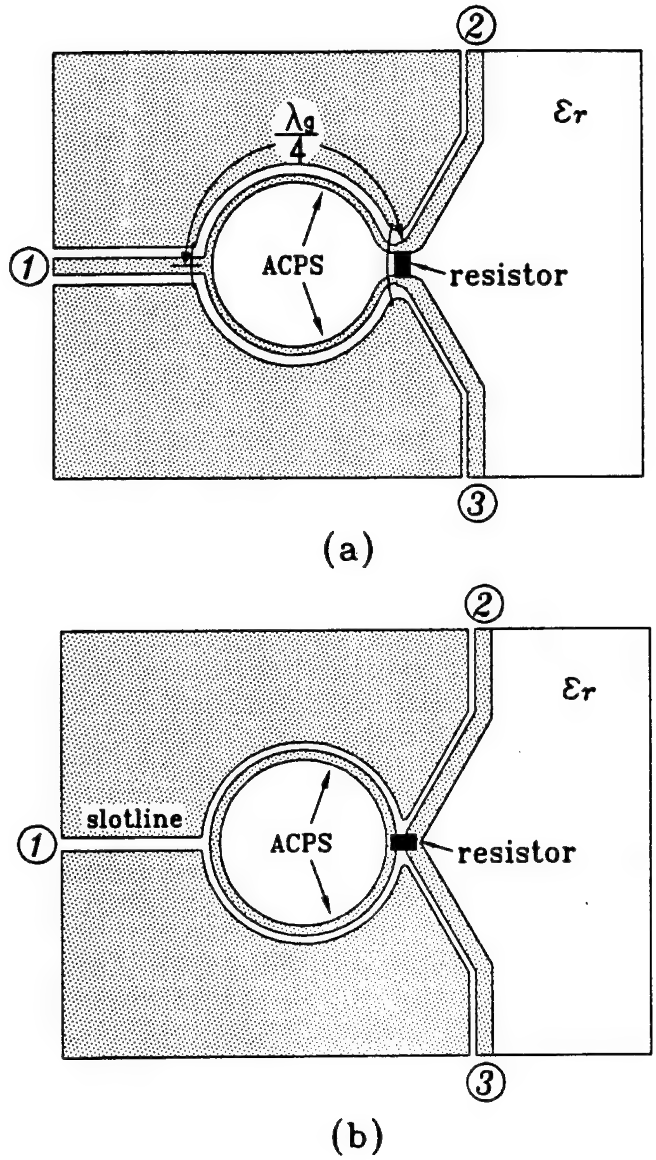

Figure 5. (a) In-phase and (b) 180° out-of-phase power dividers using asymmetrical coplanar strip (ACPS) lines.

3. List of Publications

3.1. Book Chapter Publications

B1. J. A. Navarro and K. Chang, "Active microstrip antennas" Chapter in *Advances in Microstrip and Printed Antennas*, Edited by K. F. Lee, John Wiley, 1997, pp. 371-441.

3.2. Journal Publications

J1. R. A. Flynt, L. Fan, J. A. Navarro, and K. Chang, "Low cost and compact active integrated antenna transceiver for system applications," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-44, no. 10, pp. 1642-1649, Oct. 1996.

J2. Z. Ding and K. Chang, "Modes and their stability of asymmetric two-element coupled negative conductance driven spatial power combining array," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-44, no. 10, pp. 1628-1636, Oct. 1996.

J3. L. Fan and K. Chang, "A 180° out-of phase power divider using asymmetrical coplanar stripline," *IEEE Microwave and Guided Wave Letters*, vol. 6, no. 11, pp. 404-406, Nov. 1996.

J4. L. Fan and K. Chang, "Uniplanar power dividers using coupled CPW and asymmetrical CPS for MIC's and MMIC's," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-44, no. 12, pp. 2411-2420, Dec. 1996.

J5. C. M. Montiel, L. Fan, and K. Chang, "A novel active antenna with self-mixing and wideband varactor-tuning capabilities for communication and vehicle identification applications," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-44, no. 12, pp. 2421-2430, Dec. 1996.

3.3. Conference Publications

C1. S. J. Chung and K. Chang, "Antennas integrated with microwave solid-state devices," *Progress in Electromagnetics Research Symposium (PIERS '97)*, Hong Kong, January, 1997.

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4. List of Personnel

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	J. A. Navarro
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Master of Science:	R. A. Flynt
	B. R. Heimer
	A. Kolsrud
Ph. D.:	Z. Ding
	C. M. Montiel
	J. A. Navarro

5. Report of Inventions

There is no invention to be reported.

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